A MODEL OF FLEET DEFENSE BY INTERCEPTOR AIRCRAFT

By Wilfred Palmer

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CNA RESEARCH CONTRIBUTION NO. 147

OPERATIONS EVALUATION GROUP

CENTER FOR NAVAL ANALYSES

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INTERCEPTOR AIRCRAFT

By Wilfred Palmer

April 1970

Work conducted under contract N00014-68-A-0091

Enclosure (1) to
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ABSTRACT

This research contribution describes an iterative Monte-Carlo computer simulation of fleet defense by carrier-based aircraft. The model is completely general in regard to the size of the committed forces and the capabilities of their weapons, and it allows some diversity in the composition of the defending interceptor force. It also permits consideration of a variety of tactical options.

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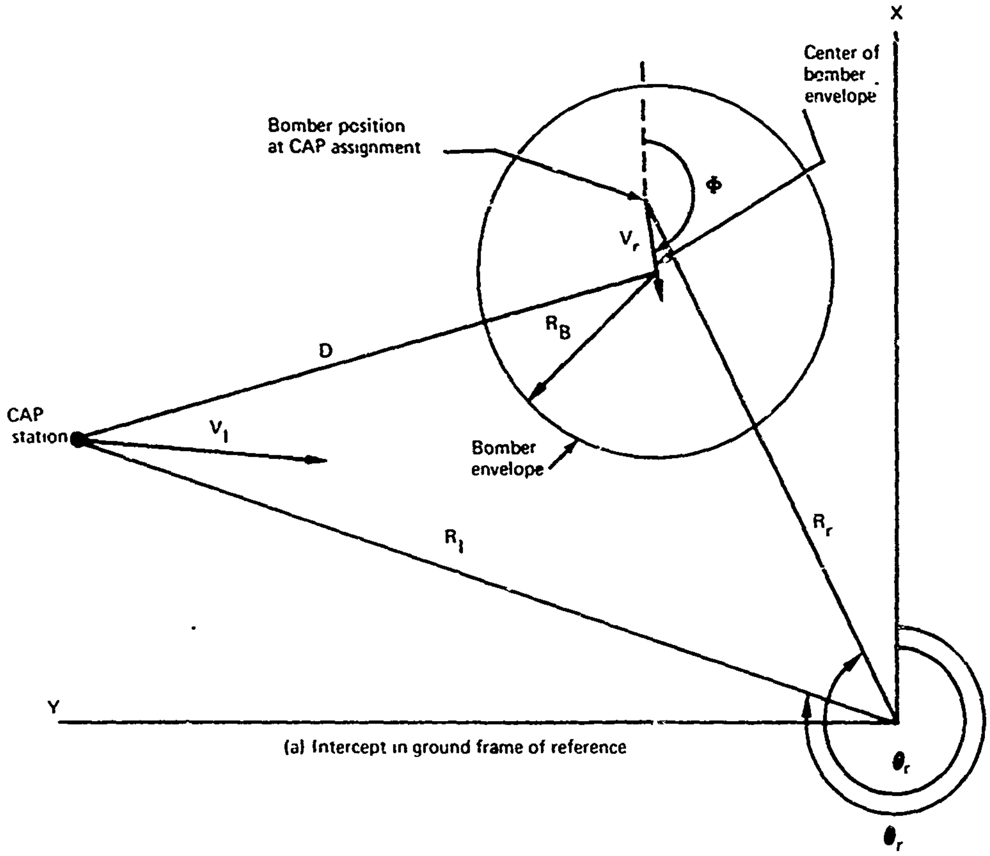
DESCRIPTION OF THE ENGAGEMENT

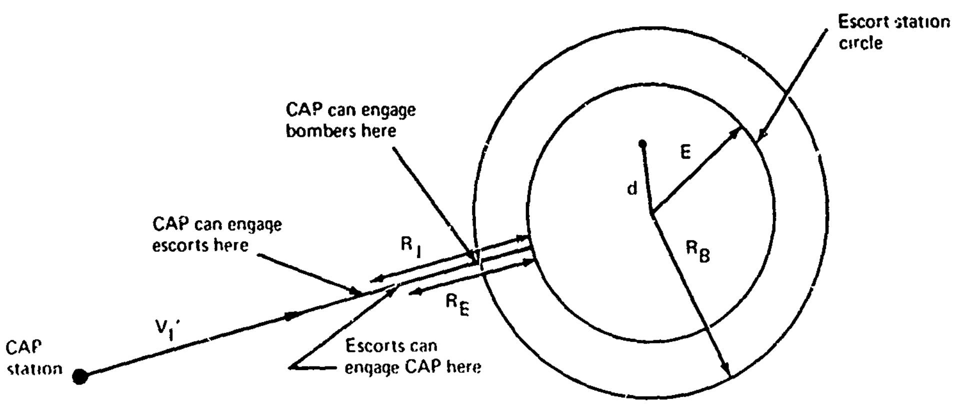
A raid consisting of an arbitrary number of enemy bombers and escorts is assumed to proceed at a specified speed along some straight path. Surrounding the bomber force is an envelope within which penetrating interceptors may attack the bombers with missiles. This envelope is approximated in the two-dimensional representation of the model by a circle whose radius, R_B, depends upon the range of the interceptor missiles and the formation of the bombers. Because of the greater range of air-to-air missiles from the head-on aspect than from tail-on, the center of the envelope is displaced a distance d along the raid direction from the mean position of the bombers (see figure 1). Escorts (one type only), if any, are positioned some distance (escort station distance E) from the center of this envelope so as to make it impossible for CAP interceptors to attack the bomber force without envountering return fire. It is further assumed that the defensive screen of the escorts is sufficiently coordinated that an approaching interceptor becomes engageable by its proper share of the escort force at some distance from the center of the bomber envelope. Similarly, this portion of the escort force becomes engageable by the interceptor at another distance from the center.* The distances are the sum of the escort station distance and the appropriate head-on escort or CAP missile range, R_E or R_I. (The head-on range of CAP missiles against maneuverable escorts will likely be less than that against bombers.)

Following detection of the raid by the fleet, CAP aircraft (of as many as two types) on specific stations are assigned to the raid at various times provided by input. The assigned CAP are vectored along the shortest route to the bomber envelope. Strict justification of this procedure requires that two conditions be fully met: 1) that CAP stations are not so close to the SAM zone boundary that a straight path from the station of an engageable interceptor to the bomber envelope would pass within the SAM zone, and 2) that the point of arrival a the bomber envelope prescribed by shortest-route vectoring is outside the SAM zone at the time of arrival. Astute CAP stationing will insure satisfaction of the first condition, and failure of the second condition has only minor consequences. If the projected point of arrival of the interceptor at the bomber envelope by shortest-route vectoring lies within the SAM zone, the interceptor would ideally be vectored instead to that point on the bomber envelope which it would reach as this this point entered the SAM zone. The additional distance the interceptor would travel to engagement in this unusual circumstance is at most the radius of the bomber envelope, and in most instances much less. Thus, engagement times computed on the assumption of shortest-route vectoring will rarely be in error by more than one missile flight time.

*Partition of the escort force into sections allocated to individually arriving interceptors is modeled by allowing each arriving interceptor to engage, and to be engaged by, the entire escort force. The fire each aircraft receives under this somewhat unrealistic rule is the same, on the average, as would exist if the opposing sides were divided into engagement units with uniform force ratios which fight independent battles.



(a) Intercept in ground frame of reference



(b) Intercept in moving frame of reference

FIGURE 1

After engagement has commenced, missiles are launched by each CAP and enemy escort at vulnerable targets until (a) the aircraft is destroyed, (b) it exhausts its ordnance, or (c) there are no remaining engageable targets. Individual CAP aircraft are disengaged when continued engagement with the bomber force would cause the CAP aircraft to intrude into the SAM zone of the fleet. The simulation stops when all bombers have been destroyed, or at a specific time which, although arbitrary, must be provided by input. This "stop time" can be chosen to be one of special interest, such as that at which the bomber force reaches ASM launch range. The model allows CAP and escorts which have exhausted their ordnance to remain engaged in the role of decoys, or to depart, at the discretion of the program user. By means of target selection factors specified by input, both CAP and enemy escorts can discriminate between target types when more than one type is engageable. This feature is intended to model the judgment in target selection which both sides can be expected to employ. Escorts may fire preferentially at the more menacing type of CAP aircraft if it can be recognized with some degree of consistency. CAP target selection may show a preference for either escorts or bombers, this preference reflecting in part the objectives of the CAP pilot and in part the success of the escorts in frustrating these objective.

LIMITATIONS

Several facets of air-to-air engagements are not modeled explicitly. The use of deck-launched interceptors has not been considered separately in the model, since such aircraft can readily be included by computing their times of arrival at the periphery of the SAM zone via the CAP corridor from the carrier, and treating this time as an assignment time and this point on the periphery as a CAP station. The effects of ECM can be modeled by appropriate adjustments of salvo rates, missile kill probabilities and CAP aircraft speed. Fuel shortages are not considered, it being assumed that prevailing CAP cycling practice permits aircraft on station to perform any mission which might conceivably be required.

Mixed ordnance loads have also not been considered. Where several types of ordnance are usable on a single aircraft, they may be accurately replaced by a single ordnance type with a salvo rate equal to the observed salvo rate for the aircraft with a mixed load, and a kill probability equal to the average of the kill probabilities of the individual ordnance types weighted according to the relative frequency of use. A composite salvo of this sort will give reliable simulation results except in situations where not all of the loaded ordnance types can be used, as will be the case before an approaching target reaches the maximum range of the shortest range weapon. These periods should be inconsequential unless there are large differences in the maximum ranges coupled with large differences in salvo rate or kill probability.

Computer programming requires specification of the maximum sizes of the CAP and escort forces, and the maximum number of engagement iterations. The program for the model as now written sets these limits at 50 CAP, 50 escorts and 20 iterations.

INPUTS

The data required by the program is entered in 4 groups. The first entry group contains

Group I
- a) the initial random number,
- b) the stop time (in minutes), and
- c) the desired number of program iterations.

This data is supplied on a single card in the format (2F10.0, I5). The initial random number is required by the random number computer routine, which uses in the generation of a random number the value of the previous number.

The second entry group contains

Group II
- a) the number of bombers,
- b) R_r, the range of the center of the bomber force at time t = 0, (in miles)
- c) Θ_r, the bearing of the center of the bomber force at time t = 0, (in degrees)
- d) Φ , the raid heading (in degrees),
- e) V_r, raid speed (in knots), and
- f) the distance from raid position at t = 0 to the SAM zone (in miles).

This data is provided on a single card in the format (I10, 5F10.0).

The next entry group defines the combat capabilities of the escorts and consists of

Group III
- a) the number of escorts,
- b) the number of salvos per fully-loaded escort,
- c) the salvo rate per escort (the reciprocal of the average time in seconds between firings separated by a damage assessment and, if necessary, acquisition of a new target),
- d) the kill probability per salvo against CAP type 1,
- e) the kill probability per salvo against CAP type 2,
- f) R_E, the escort missile range against a target in head-on aspect, (in thousands of feet)
- g) E, the escort station distance (in thousands of feet), and
- h) the target selection factor for escorts.

This data is supplied on a single card in the format (2I10, 6F10.0). The second item (b) is entered in an array listing the number of salvos remaining for each escort.

The final entry group specifies the following data for each CAP aircraft:

Group IV

a) the aircraft type (1 or 2),
b) t_a, the assignment time (in minutes),
c) R_I, the range at assignment time, (in miles)
d) θ_I, the bearing at assignment time (in degrees),
e) V_I, the speed to engagement (in knots),
f) R_B, the envelope radius for bombers (in thousands of feet),
g) d, the envelope displacement for bombers (in thousands of feet),
h) R_I, the missile range against maneuvering escorts in approximately head-on aspect (in thousands of feet),
i) the number of salvos fully loaded,
j) the salvo rate (per second),
k) the kill probability per salvo against escorts,
l) the kill probability per salvo against bombers, and
m) the CAP target selection factor.

This data is supplied on a separate card for each CAP aircraft in the format (13F6.0). A blank card follows the CAP data deck. The data is entered in the array CAP (I, J) whose elements are defined in table I. Four engagement times, CAP (I, 13), CAP (I, 14), CAP (I, 15, and CAP (I, 16) are calculated in the program; status indicators CAP (I, J), $17 \leq J \leq 22$, are set at the beginning of each iteration of a simulation and are modified as the need arises.

CALCULATIONS

The logical structure of the program is indicated in the flowchart of appendix A. Several calculations are performed in the program, and those whose nature is not self-evident are explained below. (Comprehension of the following discussion will be facilitated by reference to figure 1.)

Calculation of CAP Engagement Times

The position of the center of the bomber envelope at the time a CAP is assigned to the raid is, in a Cartesian coordinate system (X axis, north; Y axis, west),

$$X_c = R_r \cos \theta_r + (V_r t_a + d) \cos \Phi \tag{1}$$

$$Y_c = - \left[R_r \sin \theta_r + (V_r t_a + d) \sin \Phi\right] \tag{2}$$

where R_r is the range and θ_r the bearing of the center of the bomber force at t=o, Φ is the raid heading, V_r is the raid speed, t_a is the assignment time, and d is the displacement of the envelope center from the center of the bomber force. The coordinates of the assigned CAP are

$$X_I = R_I \cos \theta_I \tag{3}$$

TABLE I

Array CAP (I, J)

CAP (I, 1)	=	Aircraft type
CAP (I, 2)	=	Assignment time
CAP (I, 3)	=	Range at assignment time
CAP (I, 4)	=	Bearing at assignment time
CAP (I, 5)	=	Speed to Engagement
CAP (I, 6)	=	Envelope radius for bombers
CAP (I, 7)	=	Envelope displacement
CAP (I, 8)	=	Missile range against escorts
CAP (I, 9)	=	Number of salvos fully loaded
CAP (I, 10)	=	Salvo rate
CAP (I, 11)	=	Kill probability of salvo against escorts
CAP (I, 12)	=	Kill probability of salvo against bombers
CAP (I, 13)	=	Target selection factor for CAP
CAP (I, 14)	=	Time CAP can fire at escorts
CAP (I, 15)	=	Time escorts can fire at CAP
CAP (I, 16)	=	Time CAP can fire at bombers
CAP (I, 17)	=	Time CAP disengages
CAP (I, 18)	=	Operating (1)/Killed (0)
CAP (I, 19)	=	Engaged offensively with escorts (1)/Unengaged (0)
CAP (I, 20)	=	Engaged defensively with escorts (1)/Unengaged (0)
CAP (I, 21)	=	Engaged with bombers (1)/Unengaged (0)
CAP (I, 22)	=	Armed (1)/Unarmed (0)
CAP (I, 23)	=	Number of salvos remaining

$$Y_I = -R_I \sin \theta_I \tag{4}$$

where R_I is the range and θ_I is the bearing of the CAP at t_a. In a frame of reference which leaves the raid at rest, the distance the CAP must travel to the center of the bomber envelope is

$$D = \sqrt{(X_C - X_I)^2 + (Y_C - Y_I)^2} \tag{5}$$

The distance the CAP must travel to engage the bombers is

$$D_b = D - R_B, \tag{6}$$

where R_B is the radius of the envelope within which bombers are vulnerable. The distance the CAP must travel to engage the escorts is

$$D_e = D - E - R_I, \tag{7}$$

where E is the escort station distance and R_I is the range of the CAP missile against escorts in a head-on aspect. The CAP becomes engagable by escorts after traveling a distance

$$D_I = D - E - R_E, \tag{8}$$

where R_E is the range of the escort missile. The speed of the CAP in the moving frame of reference, V_I', must satisfy the relation

$$(\vec{V_I'} + \vec{V_r})^2 = V_I^2, \tag{9}$$

where V_I is the ground speed of the CAP. This condition may be rewritten

$$V_I'^2 + 2\,(V_{Ix}'\ V_{rx} + V_{Iy}'\ V_{ry}) + V_r^2 =$$

$$V_I'^2 + 2V_I'V_r\ \left[(X_C - X_I)\cos\Phi - (Y_C - Y_I)\sin\Phi\right]/D + V_r^2 = V_r^2 = V_I^2. \tag{10}$$

Solving for V_I', one obtains

$$V_I' = -B + \sqrt{B^2 + V_I^2 - V_r^2}, \tag{11}$$

where:

$$B = [(X_C - X_I) V_r \cos\Phi - (Y_C - Y_I) V_r \sin\Phi]/D. \tag{12}$$

The engagement times are thus

$$\text{CAP (I, 14)} = D_e/V_I' \tag{13}$$

$$\text{CAP (I, 15)} = D_I/V_I' \tag{14}$$

$$\text{CAP (I, 16)} = D_b/V_I'. \tag{15}$$

Calculation of CAP Disengagement Times

The CAP is disengaged when the center of the bomber force moves a distance (R_B - d) within the missiles-free zone. This criterion for disengagement is strictly valid only when the heading of the raid is perpendicular to the missiles-free zone boundary, a condition which should usually be met, at least approximately. Serious departures from normal entry can be taken account of by the use of an adjusted boundary. If the distance from the raid location at t = O to the SAM zone is D_s, the disengagement time is

$$\text{CAP (I, 17)} = (D_s + R_B - d)/V_r. \tag{16}$$

Identification of Firing Aircraft

The probability that a given aircraft fires a salvo is assumed to be proportional to its salvo rate, providing it has an engagable target. This assumption is the basis for determining which side, and ultimately which individual aircraft, is responsible for a given salvo. The ratio of the total salvo rate of all engaged and armed CAP aircraft to the total salvo rate for all engaged and armed aircraft, both CAP and escorts, is computed. A random fractional number is obtained, and the salvo is attributed to CAP or escorts according to whether the number is less than or greater than the computed ratio. If the salvo is fired by escorts, this number is used to identify the firing aircraft. If the salvo is fired by CAP, a second random number is compared with the appropriate salvo rate ratio to determine the type of CAP aircraft responsible for the salvo. This number is then used to identify the firing aircraft.

Target Selection

Where N_1 targets of type 1 and N_2 targets of type 2 are engagable, the ratio $N_1/(N_1 + \sigma N_2)$ is computed, σ being the target selection factor for the firing aircraft. A random fractional number is obtained, and if it is greater than this ratio, a target of type 2 is selected. Otherwise a target of type 1 is assumed. Target selection factors are evaluated on the supposition that CAP aircraft regard bombers and escorts, and escorts regard CAP type 1 and CAP type 2, as targets of types 1 and 2, respectively.

Kill Assessment

A random fractional number is obtained, and if it does not exceed the appropriate kill probability for the salvo, a kill is credited. Where the target is CAP or escorts, the random number is also used to identify the downed aircraft.

Time Advancement

Following the salvo whose effects are evaluated between points B and K in the flowchart, the time interval to the next salvo is calculated. This delay is computed on the assumption that the probability that a salvo is fired within any small time interval Δt is $S\,\Delta t$, where S is the total average salvo rate of all aircraft which remain operating and armed after the previous salvo. The assumption that this probability depends upon time only through the value of the salvo rate produces a Poisson cumulative distribution of delays δ, namely

$$\Pr\left| \delta < \delta_0 \right| = 1 - e^{-S\delta_0}. \tag{17}$$

This assumption is almost certainly incorrect for a single aircraft; following the firing of a salvo, there is a period in which another salvo cannot be fired by this particular aircraft either because of the need to assess damage or to acquire another target. Thus for a single aircraft, extremely short delays do not occur. Moreover, extremely long delays should not occur, even though they are recognized as possible in equation (17). Equation (17) therefore cannot accurately represent the form of the distribution of delays for a single aircraft. However, a knowledge of the proper distribution is not needed to generate an acceptably accurate distribution of the time required to fire a given number of salvos. Any distribution of delays for an individual aircraft which does not reflect near regularity in the salvo interval will generate the same distribution of times required for a given number of salvos as the distribution of equation (17), except at times which are so short as to be comparable to the average time required to fire a single salvo. If the number of salvos is not small, errors in the distribution at such short times will be of little consequence. If the interval between salvos is quite irregular, as should be the case in a combat situation,

a distribution of required times accurate enough for the purposes of the model can be expected after only two salvos. For this reason, equation (1) can be taken as the cumulative distribution of delays without risk of serious error.

The delay is determined in the following manner. A random fractional number R is procured, and the delay δ is computed from the relation

$$\delta = - \left[\log (1 - R) \right] / S \ . \tag{18}$$

The value of δ obtained in this way has the distribution defined by equation (17).

OUTPUT

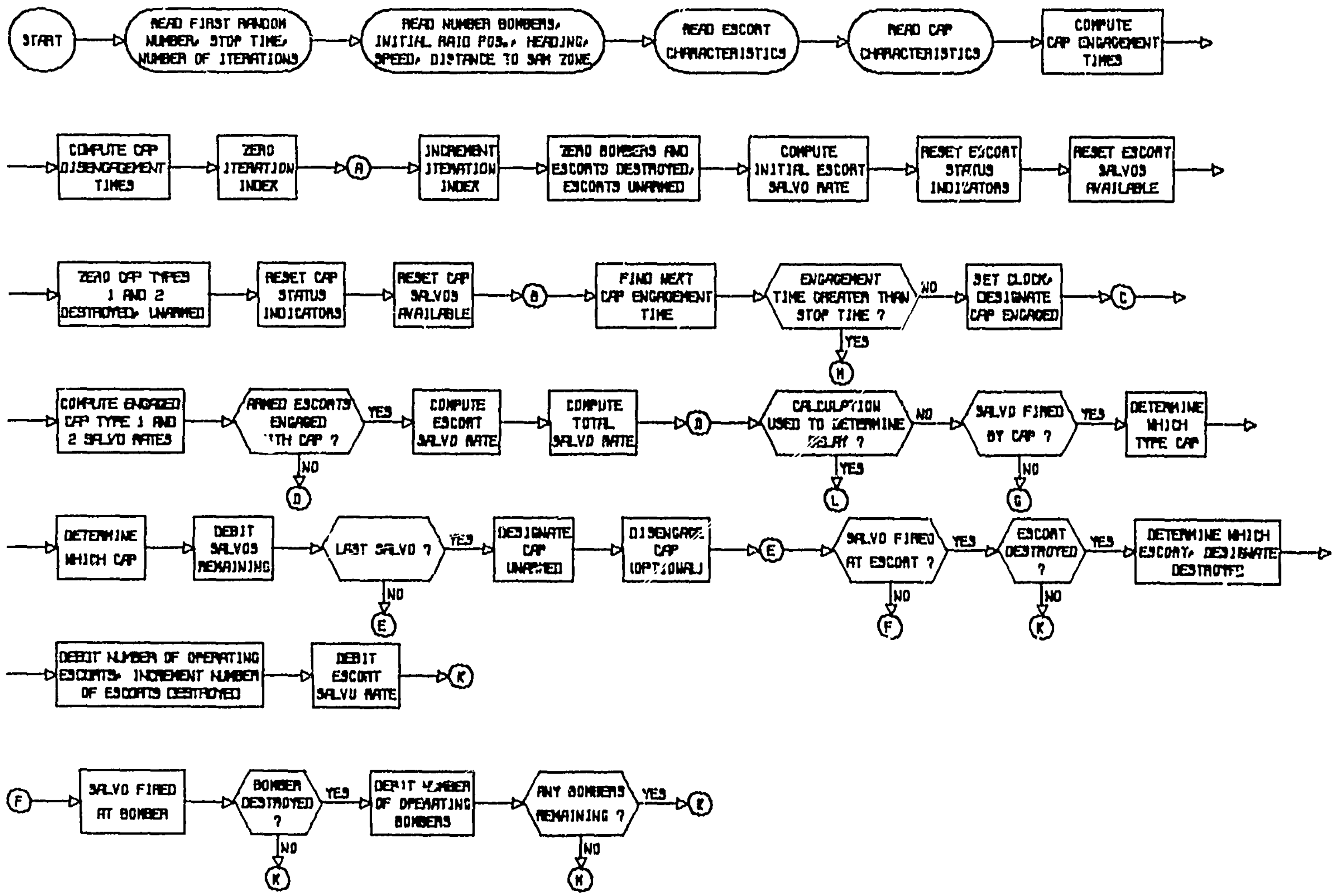
After completion of the desired number of iterations, the number of escorts, bombers, and CAP of both types destroyed, together with the numbers of escorts and CAP which have exhausted their ordnance, is printed for each iteration. The mean and standard deviation of each of these quantities is then computed and printed.

APPENDIX A

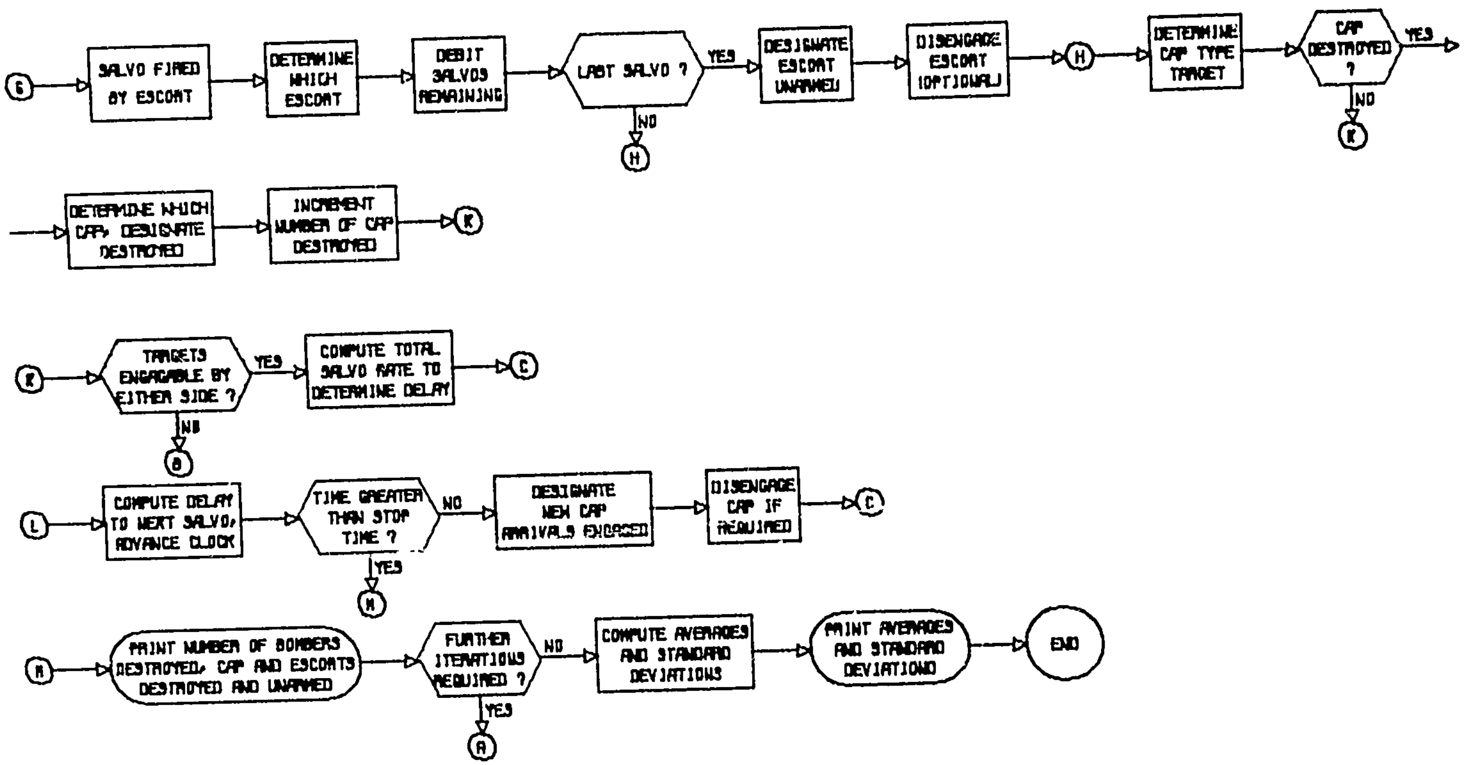
APPENDIX A

FLOW CHART OF AIR-TO-AIR ENGAGEMENT MODEL

PROGRAM AIRAIR



PROGRAM AIRAIR



APPENDIX B

APPENDIX B

FORTRAN LISTING OF MODEL PROGRAM

```
      PROGRAM AIRAIR
      DIMENSION CAP(50,23), ESCARM(50), ESCOP(50), NESRSL(50),
     1   NCDES1(20), NCDES2(20), NCPUL1(20), NCPUL2(20), NESDES(20),
     2   NESUNL(20), NBOMDS(20)
      READ 10, RANONE, TSTOP, ITERAT
   10 FORMAT (2F10.0,I5)
      READ 11, NBOMB, RGRAD, BRGRAD, HDGRAD, VRAD, DISTSM
   11 FORMAT (I10, 5F10.0)
      READ 14, NESC, NESCSL, ESCSLR, ESCPK1, ESCPK2, ESCMRG, ESCSTA,
     1   ESTSFI
   14 FORMAT (2I10, 6F10.0)
      DO 15 I=1,50
      READ 16, (CAP(I,J), J=1,13)
   16 FORMAT (13F6.0)
      IF (CAP(I,5).EQ.0.) GO TO 17
   15 CONTINUE
   17 NCAP=I-1
      NCAP1=0
      NCAP2=0
      MBOMDS=0
      MESDES=0
      MESUNL=0
      MCDES1=0
      MCDES2=0
      MCPUL1=0
      MCPUL2=0
      SSBOMDS=0.
      SSESDES=0.
      SSESUNL=0.
      SSCDES1=0.
      SSCDES2=0.
      SSCPUL1=0.
      SSCPUL2=0.
      DO 18 I=1,NCAP
      IF (CAP(I,1).GT.1.) GO TO 20
      NCAP1=NCAP1+1
      GO TO 18
   20 NCAP2=NCAP2+1
   18 CONTINUE
      XRAD=RGRAD*COSF(BRGRAD/57.29578)
      YRAD=-RGRAD*SINF(BRGRAD/57.29578)
      VXRAD=VRAD*COSF(HDGRAD/57.29578)
      VYRAD=-VRAD*SINF(HDGRAD/57.29578)
C     COMPUTE ENGAGEMENT AND DISENGAGEMENT TIMES
      DO 25 I=1,NCAP
      XCENAS=XRAD+(VRAD*CAP(I,2)/60.+CAP(I,7)/6.076)*COSF(HDGRAD/
     1   57.29578)
      YCENAS=YRAD-(VRAD*CAP(I,2)/60.+CAP(I,7)/6.076)*SINF(HDGRAD/
```

```
 1   57,29578)
     XCAPAS=CAP(I,3)*COSF(CAP(I,4)/57,29578)
     YCAPAS=-CAP(I,3)*SINF(CAP(I,4)/57,29578)
     DIST=SQRTF((XCENAS-XCAPAS)**2+(YCENAS-YCAPAS)**2)
     B=((XCENAS-XCAPAS)*VXRAD+(YCENAS-YCAPAS)*VYRAD)/DIST
     VCAPMV=-B+SQRTF(B**2+CAP(I,5)**2-VRAD**2)
     CAP(I,15)=CAP(I,2)+(DIST-CAP(I,6)/6,076)/(VCAPMV/60,)
     CAP(I,14)=CAP(I,4)+(DIST-(ESCSTA+CAP(I,8))/6,076)/(VCAPMV/60.)
     CAP(I,15)=CAP(I,2)+(DIST-(ESCSTA+ESCMRG)/6,076)/(VCAPMV/60.)
  25 CAP(I,17)=(DISTSM+(CAP(I,6)-CAP(I,7))/6,076)/(VRAD/60,)
     CALL RANSET (RANCNE)
C    FLOW CHART JUNCTION A
     DO 1000 ITIND=1,ITERAT
     NBOMRO=NBOMB
     NBOMPS(ITIND)=0
     NESCOR=NESC
     NESCOL=NESC
     NESDES(ITIND)=0
     NESJNL(ITIND)=0
     NDELAY=0
     ESCOL=NESCOL
     TSRESC=ESCOL*ESCSLR
     DO 26 I=1,NESC
     ESCARM(I)=1.
     ESCOP(I)=1.
  26 NESRSL(I)=NESCSL
     NCDES1(ITIND)=0
     NCDES2(ITIND)=0
     NCPUL1(ITIND)=0
     NCPUL2(ITIND)=0
     DO 28 I=1,NCAP
     CAP(I,13)=1.
     CAP(I,19)=0.
     CAP(I,20)=0.
     CAP(I,21)=0.
     CAP(I,22)=1.
  28 CAP(I,23)=CAP(I,9)
     TIME=0.
C    FLOW CHART JUNCTION B
C    DETERMINE NEXT ENGAGEMENT TIME
  29 TEMP=1,E9
     DO 32 I=1,NCAP
     IF (NESCO,EQ,0) GO TO 32
     IF (CAP(I,14)+CAP(I,18)+CAP(I,22),LE,TIME) GO TO 35
     IF (CAP(I,14),GE,TEMP) GO TO 35
     TEMP=CAP(I,14)
  35 IF (NESCOL,EQ,0) GO TO 32
     IF (CAP(I,15)+CAP(I,18),LE,TIME) GO TO 32
```

```
      IF (CAP(I,15).GE.TEMP) GO TO 32
      TEMP=CAP(I,15)
   32 IF (CAP(I,16)+CAP(I,18)+CAP(I,22).LE.TIME) GO TO 30
      IF (CAP(I,16).GE.TEMP) GO TO 30
      TEMP=CAP(I,16)
   30 CONTINUE
      TIME=TEMP
      IF (TIME.GT.TSTOP) GO TO 100
      DO 40 I=1,NCAP
      DO 40 J=14,16
      IF (CAP(I,J).NE.TIME) GO TO 40
      CAP(I,J+5)=1.
   40 CONTINUE
C     FLOW CHART JUNCTION C
C     DETERMINE WHICH SIDE SHOOTS
   41 NTEST=0
      CPEOL1=0.
      CPEOL2=0.
      IF (NESC0.GT.0) GO TO 46
      DO 45 I=1,NCAP
      IF (CAP(I,1).GT.1) GO TO 43
      CPEOL1=CPEOL1+CAP(I,21)*CAP(I,22)*CAP(I,18)
      SRCAP1=CAP(I,10)*CPEOL1
      GO TO 45
   43 CPEOL2=CPEOL2+CAP(I,21)*CAP(I,22)*CAP(I,18)
      SRCAP2=CAP(I,10)*CPEOL2
   45 CONTINUE
      GO TO 50
   46 DO 48 I=1,NCAP
      IF (CAP(I,20)*CAP(I,18).EQ.1.) NTEST=1
      IF (CAP(I,1).GT.1.) GO TO 47
      CPEOL1=CPEOL1+(CAP(I,19)+CAP(I,21)-CAP(I,19)*CAP(I,21))*CAP(I,22)*
     1   CAP(I,18)
      SRCAP1=CAP(I,10)*CPEOL1
      GO TO 48
   47 CPEOL2=CPEOL2+(CAP(I,19)+CAP(I,21)-CAP(I,19)*CAP(I,21))*CAP(I,22)*
     1   CAP(I,18)
      SRCAP2=CAP(I,10)*CPEOL2
   48 CONTINUE
      IF (NESC0L.EQ.0) GO TO 50
      IF (NTEST.EQ.0) GO TO 50
      TSR=SRCAP1+SRCAP2+TSRESC
      IF (NDELAY.EQ.1) GO TO 97
      TESTCE=(SRCAP1+SRCAP2)/TSR
      CALL RANUMB(X)
      IF (X.GT.TESTCE) 75,52
C     FLOW CHART JUNCTION D
   50 TSR=SRCAP1+SRCAP2
```

```
   51 IF (NDELAY.EQ.1) GO TO 97
C        CAP SHOOTS
   52 TEST12=SRCAP1/(SRCAP1+SRCAP2)
      CALL RANUMB(X)
      IF (X.GT.TEST12) GO TO 56
C        CAP TYPE 1 SHOOTS
      NZONE=(IPEOL1*X/TEST12)+1.
      K=0
      DO 55 M=1,NCAP
      IF (CAP(M,1).NE.1.) GO TO 55
      IF (NESCO.EQ.0) GO TO 53
      J=(CAP(M,19)+CAP(M,21)-CAP(M,19)*CAP(M,21))*CAP(M,18)*CAP(M,22)
      GO TO 54
   53 J=CAP(M,21)*CAP(M,18)*CAP(M,22)
   54 K=K+J
      IF (K.EQ.NZONE) GO TO 60
   55 CONTINUE
C        CAP TYPE 2 SHOOTS
   56 NZONE=(IPEOL2*(1.-X)/(1.-TEST12))+1.
      K=0
      DO 57 M=1,NCAP
      IF (CAP(M,1).NE.2.) GO TO 57
      IF (NESCO.EQ.0) GO TO 58
      J=(CAP(M,19)+CAP(M,21)-CAP(M,19)*CAP(M,21))*CAP(M,18)*CAP(M,22)
      GO TO 59
   58 J=CAP(M,21)*CAP(M,18)*CAP(M,22)
   59 K=K+J
      IF (K.EQ.NZONE) GO TO 60
   57 CONTINUE
   60 CAP(M,23)=CAP(M,23)-1.
      IF (CAP(M,23).NE.0.) GO TO 63
      CAP(M,22)=0.
      IF (CAP(M,1).GT.1.) GO TO 61
      NCPUL1(ITIND)=NCPUL1(ITIND)+1
      GO TO 62
   61 NCPUL2(ITIND)=NCPUL2(ITIND)+1
   62 CONTINUE
C        DISENGAGE EMPTY CAP WITH NEXT CARD (500)
  500 CAP(M,18)=0.
C        FLOW CHART JUNCTION E
C        CAP SHOOTS AT BOMBER OR ESCORT
   63 IF (CAP(M,19).EQ.0.) GO TO 70
      IF (NESCO.EQ.0)  0 TO 70
      IF (CAP(M,21).EQ.0.) GO TO 65
      BOMBO=NBOMBO
      ESCO=NESCO
      TESTEB=BOMBO/(BOMBO+CAP(M,13)*ESCO)
      CALL RANUMB(X)
      IF (X.LE.TESTEB) GO TO 70
```

```
C        CAP SHOOTS AT ESCORT
     65 CALL RANUMB(X)
        IF (X.GT.CAP(M,11)) GO TO 90
        NZONE=(ESCO*X/CAP(M,11))+1.
        K=0
        DO 66 N=1,NESC
        J=ESCOP(N)
        K=K+J
        IF (K.EQ.NZONE) GO TO 67
     66 CONTINUE
     67 ESCOP(N)=0.
        NESCO=NESCO-1
        NESCOL=NESCOL-1
        NESDES(ITIND)=NESDES(ITIND)+1
        TSRESC=TSRESC-ESCSLR*ESCARM(N)
        GO TO 90
C        FLOW CHART JUNCTION F
C        CAP SHOOTS AT BOMBER
     70 CALL RANUMB(X)
        IF (X.GT.CAP(M,12)) GO TO 90
        NBOMBO=NBOMBO-1
        NBOMDS(ITIND)=NBOMDS(ITIND)+1
        IF (NBOMBO.EQ.0) 100,90
C        FLOW CHART JUNCTION G
C        ESCORT SHOOTS
     75 ESCOL=NESCOL
        CALL RANUMB(X)
        NZONE=(ESCOL*X)+1.
        K=0
        DO 76 L=1,NESC
        J=ESCARM(L)*ESCOP(L)
        K=K+J
        IF (K.EQ.NZONE) GO TO 77
     76 CONTINUE
     77 NESRSL(L)=NESRSL(L)-1
        IF (NESRSL(L).NE.0) GO TO 78
        ESCARM(L)=0.
        NESUNL(ITIND)=NESUNL(ITIND)+1
        TSRESC=TSRESC-ESCSLR
        NESCOL=NESCOL-1
C        DISENGAGE UNARMED ESCORT WITH FOLLOWING CARDS (600,601)
    600 ESCOP(L)=0.
    601 NESCO=NESCO-1
C        FLOW CHART JUNCTION H
C        ESCORT SHOOTS AT CAP TYPE 1 OR 2
     78 CAPDE1=0.
        CAPDE2=0.
        DO 79 I=1,NCAP
        IF (CAP(I,1).GT.1.) GO TO 80
```

```
      CAPDE1=CAPDE1+CAP(I,20)*CAP(I,18)
      GO TO 79
   80 CAPDE2=CAPDE2+CAP(I,20)*CAP(I,18)
   79 CONTINUE
      TEST12=CAPDE1/(CAPDE1+ESTSF*CAPDE2)
      CALL RANUMB(X)
      IF (X.GT.TEST12) GO TO 85
C     FSCORT SHOOTS AT CAP TYPE 1
      CALL RANUMB(X)
      IF (X.GT.ESCPK1) GO TO 90
      NZONE=(CAPDE1*X/ESCPK1)+1.
      K=0
      DO 82 I=1,NCAP
      IF (CAP(I,1).NE.1.) GO TO 82
      J=CAP(I,20)*CAP(I,18)
      K=K+J
      IF (K.EQ.NZONE) GO TO 83
   82 CONTINUE
   83 CAP(I,18)=0.
      NCDES1(ITIND)=NCDES1(ITIND)+1
      GO TO 90
C     FSCORT SHOOTS AT CAP TYPE 2
   85 CALL RANUMB(X)
      IF (X.GT.ESCPK2) GO TO 90
      NZONE=(CAPDE2*X/ESCPK2)+1.
      K=0
      DO 86 I=1,NCAP
      IF (CAP(I,1).NE.2.) GO TO 86
      J=CAP(I,20)*CAP(I,18)
      K=K+J
      IF (K.EQ.NZONE) GO TO 87
   86 CONTINUE
   87 CAP(I,18)=0.
      NCDES2(ITIND)=NCDES2(ITIND)+1
C     FLOW CHART JUNCTION K
C     TARGETS AVAILABLE TO EITHER SIDE
   90 DO 91 I=1,NCAP
      IF (CAP(I,21)*CAP(I,22)*CAP(I,18).NE.0.) GO TO 94
      IF (NESC0.EQ.0) GO TO 91
      IF (CAP(I,19)*CAP(I,22)*CAP(I,18).NE.0.) GO TO 94
      IF (NESC0L.EQ.0) GO TO 91
      IF (CAP(I,20)*CAP(I,18).NE.0.) GO TO 94
   91 CONTINUE
   93 GO TO 29
C     ADVANCE CLOCK, ADD CAP ENTRIES
   94 NDELAY=1
      GO TO 41
C     FLOW CHART JUNCTION L
   97 NDELAY=0
```

```
      CALL RANUMB(X)
      DELAY=-(LOGF(1-X))/TSR
      TIME=TIME+DELAY
      IF (TIME.GT.TSTOP) GO TO 100
      DO 98 I=1,NCAP
      DO 98 J=14,16
      IF (CAP(I,J).LE.(TIME-DELAY)) GO TO 98
      IF (CAP(I,J).GT.TIME) GO TO 98
      CAP(I,J+5)=1.
   98 CONTINUE
      DO 99 I=1,NCAP
      IF (CAP(I,17).GT.TIME) GO TO 99
      CAP(I,13)=0.
   99 CONTINUE
      GO TO 41
C     FLOW CHART JUNCTION M
  100 MBOMDS=MBOMDS+NBOMDS(ITIND)
      MESDES=MESDES+NESDES(ITIND)
      MESUNL=MESUNL+NESUNL(ITIND)
      MCDES1=MCDES1+NCDES1(ITIND)
      MCDES2=MCDES2+NCDES2(ITIND)
      MCPUL1=MCPUL1+NCPUL1(ITIND)
      MCPUL2=MCPUL2+NCPUL2(ITIND)
      Y=NBOMDS(ITIND)**2
      SSBOMDS=SSBOMDS+Y
      Y=NESDES(ITIND)**2
      SSESDES=SSESDES+Y
      Y=NESUNL(ITIND)**2
      SSESUNL=SSESUNL+Y
      Y=NCDES1(ITIND)**2
      SSCDES1=SSCDES1+Y
      Y=NCDES2(ITIND)**2
      SSCDES2=SSCDES2+Y
      Y=NCPUL1(ITIND)**2
      SSCPUL1=SSCPUL1+Y
      Y=NCPUL2(ITIND)**2
      SSCPUL2=SSCPUL2+Y
 1000 CONTINUE
C     COMPUTE AVERAGES AND STANDARD DEVIATIONS
      ABOMDS=MBOMDS/ITERAT
      AESDES=MESDES/ITERAT
      AESUNL=MESUNL/ITERAT
      ACDES1=MCDES1/ITERAT
      ACDES2=MCDES2/ITERAT
      ACPUL1=MCPUL1/ITERAT
      ACPUL2=MCPUL2/ITERAT
      X=ITERAT
      SDBOMDS=SQRTF((SSBOMDS-X*ABOMDS)/(X-1.))
      SDESDES=SQRTF((SSESDES-X*AESDES)/(X-1.))
```

```
      SDESUNL=SQRTF((SSESUNL-X*AESUNL)/(X-1,))
      SDCDES1=SQRTF((SSCDES1-X*ACDES1)/(X-1,))
      SDCDES2=SQRTF((SSCDES2-X*ACDES2)/(X-1,))
      SDCPUL1=SQRTF((SSCPUL1-X*ACPUL1)/(X-1,))
      SDCPUL2=SQRTF((SSCPUL2-X*ACPUL2)/(X-1,))
      PRINT 1051
 1051 FORMAT (69H       BOMBERS       CAP TYPE 1          CAP TYPE 2
     1        ESCORTS)
      PRINT 1052, NBOMB, NCAP1, NCAP2, NESC
 1052 FORMAT (7X,I5,9X,I6,14X,I6,15X,I5)
      PRINT 1053
 1053 FORMAT (75H0RUN  DESTROYED  DESTROYED UNLOADED  DESTROYED UNLOADED
     1  DESTROYED UNLOADED)
      DO 1055 I=1,ITERAT
      PRINT 1054, I, NBOMDS(I), NCDES1(I), NCPUL1(I), NCDES2(I),
     1   NCPUL2(I), NESDES(I), NESUNL(I)
 1054 FORMAT (1X,I2,3X,I5,6X,I5,4X,I5,6X,I5,4X,I5,6X,I5,4X,I5)
 1055 CONTINUE
      PRINT 1056
 1056 FORMAT (40H0                              AVERAGES)
      PRINT 1057, ABOMBS, ACDES1, ACPUL1, ACDES2, ACPUL2, AESDES, AESUNL
 1057 FORMAT (5X,F7.1,4X,F7.1,2X,F7.1,4X,F7.1,2X,F7.1,4X,F7.1,2X,F7.1)
      PRINT 1058
 1058 FORMAT (46H0                              STANDARD DEVIATIONS)
      PRINT 1057, SDBOMDS, SDCDES1, SDCPUL1, SDCDES2, SDCPUL2, SDESDES,
     1   SDESUNL
      END
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13 ABSTRACT

THE REPORT ~~This research contribution~~ describes an iterative Monte-Carlo computer simulation of fleet defense by carrier-based aircraft. The model is completely general in regard to the size of the committed forces and the capabilities of their weapons, and it allows some diversity in the composition of the defending interceptor force. It also permits consideration of a variety of tactical options. ()

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